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# Survey of Aircraft Icing Simulation Test Facilities in North America

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SURVEY OF AIRCRAFT ICING SIMULATION TEST  
FACILITIES IN NORTH AMERICA

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SUMMARY

A survey was made of the aircraft icing simulation facilities in North America. This was requested of NASA by several committees concerned with Aircraft Icing. A similar survey of European facilities had already been reported in AGARD advisory report 127.

There are 12 wind tunnels, 28 engine test facilities, 6 aircraft tankers and 14 low velocity facilities, that can perform various aircraft icing tests full or part time. The survey determined the location and size of the facility, its speed and temperature range, icing cloud parameters, and the technical person to contact. These results are presented in tabular form. The capabilities of each facility were estimated by its technical contact person. The adequacy of these facilities for various types of icing tests is discussed.

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## INTRODUCTION

Aircraft that fly low and slow and have small aerodynamically critical surfaces are especially sensitive to icing. Helicopters and general aviation aircraft exactly fit this worst case description. Significant activity in the aircraft icing field is expected because a large number of these aircraft are expected to be developed to fly into icing conditions in the next few decades. Considerable data (both R&D and Certification) is required before any aircraft can be developed and certified as being able to fly safely through atmospheric icing conditions. Test flights in natural icing clouds are no great hardship for long range aircraft because they can rapidly fly the great distances and to the altitude required to find those elusive icing clouds. But obtaining flight data for the helicopter and GA aircraft in natural icing can be prohibitively expensive and time consuming because of their range and altitude limitations. In order to reduce our reliance upon natural icing flights for short range aircraft, improvements appear to be needed in the Aircraft Icing Simulation Facilities and in the analytical models for icing and its effects. The first step in this improvement process is to determine the capabilities and limitations of all of the existing icing simulation facilities.

NASA was requested to survey the capabilities of the facilities in North America that can do aircraft icing simulation tests. The survey was requested of NASA by the Standing Committee on Icing, which is jointly sponsored by NASA, FAA and NOAA; similar requests have also been made by the military services and AGARD. European icing facilities were not included because they have already been surveyed (ref. 1).

The reasons for the survey are to: 1. Assist the icing research community in determining the adequacy of the present mix of icing test facilities for all types of aircraft, 2. Make it easier for a potential facility user to select and contact the icing facility that is appropriate for his test requirements, and 3. Help facility managers evaluate and improve their facility.

This paper includes a short description of the various types of facilities, a detailed listing of the capabilities of each facility, and some discussion and evaluation of these capabilities. The capabilities of the facilities are presented in tabular form. The capabilities of each facility are the opinion of the technical people working with that facility. Based upon the information in the tables and additional information, cursory evaluations are then made of the adequacy of the existing facilities for the various types of icing tests. Some additional comments are also made about icing cloud instruments.

## DISCUSSION OF FACILITIES

The icing environment that an aircraft and its components must operate in is described in this section. Then the various types of icing facilities, and the tasks they are used for, are briefly described. Following that, the capabilities of the icing facilities in North America are briefly discussed along with additional information.

### Icing Environment Requirements

Aircraft flying through clouds below about 8,000 meters can be subject to the formation of ice (icing) on critical surfaces, which can cause serious losses in performance and damage, and even a crash. The ice forms from



the small supercooled droplets in these clouds (Icing Cloud Environment, ICE). At low altitudes, large supercooled droplets (Freezing Rain, FR) also result in icing. The effect of snow, and ice particles and ice chunks on the aircraft (especially the engine) must also be considered. In addition, there is a concern about mixtures of the above conditions. The range of atmospheric parameters for ICE, that are used for design and certification testing of transport aircraft, are defined in Federal Aviation Regulation (FAR) part 25, appendix C (ref. 2). These ranges of temperature, liquid water content and drop size, at various altitudes for Stratiform (layer) and Cumuliform clouds, are shown as envelopes on figure 1. These envelopes define the maximum likely ranges of these parameters that would occur in nature (i.e., 99.9 percent of the observations in nature lie within these envelopes). The aircraft manufacturer must design his aircraft to cope with every combination of the parameters represented by the envelopes, along with the mission of the aircraft (e.g., altitude, airspeed and exposure time to the ICE). From these considerations he must determine the specific ICE conditions that result in the most severe icing on each aircraft component (e.g., wings, engine inlet, etc.). These discrete conditions become the design and test conditions for icing tests of the aircraft, its components and icing protections systems. Although desirable, an icing facility doesn't have to operate over the entire range of the entire FAR 25 envelopes in order to do meaningful R&D tests and certification tests. Furthermore, some aircraft can't possibly encounter the full range of conditions indicated by figure 1. For example, the helicopter has a limited altitude capability which makes high levels of LWC extremely unlikely; indeed, reference 3 suggests that a truncation of the FAR 25 envelopes should be used for helicopters. At the other extreme, engines are designed and tested for the whole FAR 25 envelope (ref. 4), largely because they are used in a variety of aircraft. As a minimum goal, all facilities should be able to produce 20 micron droplets for any icing test of a full scale aircraft or component.

### Types of Icing Facilities and Their Uses

The types of icing test facilities and the types of icing tests are listed below.

#### FACILITIES FOR ICING TESTS

Natural icing flights

Icing simulation facilities:

A. Wind tunnels

B. Engine test facilities

a. Free jet

b. Direct connect

C. Low velocity facilities

D. Flight tests with tankers

Other icing simulation techniques



## TYPES OF ICING TESTS

Certification and R&D tests for:

Engines

Instruments

Fixed wing aircraft

Helicopters

Components of the above (including: ice protection systems, wings, etc.)

General research and technology

Natural icing flights. - Aircraft manufacturers often fly their aircraft in a broad range of natural icing conditions in order to obtain certification by the FAA as being able to fly safely in icing conditions. This is an expensive undertaking. It is reasonable for long range aircraft, because they can fly great distances to find those elusive icing clouds that are hard to find when you want them. But for short range aircraft (e.g., helicopters and civil aviation aircraft) a test program involving natural icing is all but prohibitively expensive, time consuming and uncertain (refs. 5 and 6). In any event natural icing flight tests are not discussed in this paper, which is devoted entirely to Icing Simulation Facilities.

Icing simulation facilities. - Research and Development and Technology types of tests, and much certification must largely be accomplished in one or more of the varied types of Icing Simulation Facilities. The four general types of simulation facilities and their major variations are schematically sketched on figures 2(A) to (D). The primary differences between each type of facility are in their geometry, airspeed, and in the types of tests they are used for. The general operation of all is similar; the next paragraph describes their operation in a general way.

In all icing simulation facilities, the test aircraft or component is tested in a cold airstream which contains a smaller icing cloud. The icing cloud is made up of either supercooled droplets, which freeze when they strike the test surface, or ice particles. The Icing Cloud Environment (ICE) is made up of very small supercooled droplets (10 to 50 micron diameters) which are sprayed into the cold airstream by special nozzles (generally high pressure, hot air and water). As the droplets travel in the cold airstream they cool well below the freezing temperature without freezing (i.e., they supercool). Different nozzles or other devices are used to generate the larger droplets of freezing rain (FR) and the solid ice particles (SI) respectively. The cold airstream is either cold ambient air or else it is cooled wholly (or in part) by a large refrigeration system.

Other icing simulation techniques. - Aerodynamic performance penalties caused by ice are traditionally ascertained by flying the aircraft with "plastic ice" shapes attached to the wings and tail surfaces etc. This would be more difficult to do safely with helicopter rotors. Analytical simulations are also used to a large extent. Aircraft certification is often based upon the similarity of a new aircraft or component to one



already certified. These methods are again not discussed in this paper; only icing simulation facilities are discussed.

### Description of Survey

The survey was limited to those existing North American facilities that have an icing simulation capability. In other words, they produce supercooled droplets (ICE and/or FR) in a cold moving air stream. Future icing simulation facilities are also included if they are funded or seriously proposed. It is believed that all of the facilities with ICE capability have been included, but some low velocity facilities with FR capability may have been missed.

The facilities surveyed and their capabilities are listed in tables A to D, one table for each of the four types of facilities described on figures 2(A) to (D). The capabilities of the individual facilities were estimated by the technical contact person for that facility. Preliminary tables were completed by phone; later, the applicable technical person for each facility was sent a copy of the tables to check the entries for his facility. The numbers listed in the table are single point approximations by him of the operating curves of that facility. Many of the capabilities were truncated so that comparisons would not be made between facilities on the basis of unimportant excess capabilities for aircraft icing tests.

### Description and Capabilities of Icing Simulation Facilities

As noted before, the primary differences between the various types of facilities are in their geometry, airspeed and in the types of tests run. Each type of facility is now discussed along with some comments about the capabilities of some individual facilities.

Wind tunnels. - The test section leg of a typical icing wind tunnel is schematically sketched in figure 2(A). Table A lists the icing wind tunnels in North America. Most are closed loop wind tunnels; one is a Free Jet (entry A-5) that is listed in this table because it primarily does wind tunnel type of work. There are ten (10) tunnels that are active now; a very large wind tunnel has been proposed (A-1b), but facilities (A-4a) and (A-4b) have recently been removed from the icing facility rolls. The test sections of the existing tunnels range from 1.8x2.7 meters for the largest (A-1a) to 0.15 meters for the smallest (A-6a). The highest velocity for the larger existing tunnels is 470 km/hr; one small facility (A-5) can achieve  $M = 0.8$ . Most of the existing tunnels are limited to sea level altitudes, except for the smaller ones (A-5 and A-6b). All but (A-9) produce the Icing Cloud Environment (ICE) of adequately small supercooled droplets, including the 20 micron minimum goal. Only a few of the existing tunnels produce the larger droplets of freezing rain; none produce solid ice particles (SI). None produce Snow (S) either. It should be pointed out that NRC researchers found that the best snow simulation was made by "shoveling in" loosely packed natural snow. The LWC range, and the size of the uniform icing cloud are generally adequate. All of these facilities have refrigeration so that they can be run all year; in addition, most are dedicated to full time icing testing. The existing wind tunnels are ideally suited for research and development type tests. Certification testing at the most severe icing conditions can often be performed. But none of the wind tunnels can cover the entire FAR 25 envelope, or the entire altitude and velocity range of test aircraft. Furthermore, the tunnels are relatively small so that only



components of the aircraft are usually tested (e.g., inlets, tail section etc.). Helicopter rotors are simply too large. Icing scaling laws are often used to convert tunnel results to the size, airspeed and altitude of the test aircraft (ref. 7), and to account for the deficiencies in the LWC and drop size of the cloud. Unfortunately, these scaling laws have not been adequately verified experimentally.

Engine test facilities. - Table B indicates that there are 28 active engine test facilities that can do engine icing tests; in addition, a large engine test facility (B-1c) is planned for 1983. These are all engine test facilities that do icing tests on a test engine as part of the test program; icing tests account for about 10 percent of the test program for each engine.

There are two basic types of engine test facilities: the Free Jet (fig. 2-B(a)) and the Direct Connect (fig. 2-B(b)). Many of the engine test facilities can be configured to be run either way. In the Free Jet mode, the airstream from the nozzle (i.e. the jet) passes around and through the engine. In the Direct Connect mode, the nozzle is extended to the engine inlet so that all of the airstream passes through the engine.

A number of these facilities are large and can attain high airspeeds and altitudes (e.g., B-1a, B-1c, B-6b, and B-6c). The largest of the high speed Free Jets has a five foot diameter nozzle (B-1(b)). There is also a very large Free Jet (B-3) but it is limited to very low velocities.

The largest of the present engine facilities are too small to handle very large jet engines or large turboprops. Facilities that can presently handle G/A propeller engines are limited in number (e.g., B-9). This problem is discussed in more detail in a later section.

All facilities produce an icing cloud environment (ICE). Only a few of the facilities produce solid ice (SI) particles none produce snow. Most have refrigeration so that they can be run all year. Comparing all the capabilities of the Engine Test Facilities listed in table B with the Certification requirements, indicates that Certification tests can be performed for engines in most of these facilities over the entire FAR 25 certification envelope. The LWC in the cloud is reported to be adequately uniform across most of the flow.

The Free Jet can be used for many icing experiments that would normally be performed in wind tunnels, especially those with test surfaces that are short enough axially to stay within the potential core of the jet (cone shaped region of uniform velocity and low turbulence that is about four nozzle diameters long). The air speed and altitude capability of some of these facilities (e.g. B-1b) are excellent.

Low velocity facilities. - There are 14 existing facilities listed on table C. One will be mothballed by 1985 (C-1). All operate at a low velocity. All have FR capability; the first seven (7) can also produce the ICE. Most of these facilities are used for typical cold room tests of equipment and personnel in a ground level environment (cold air at low velocity); aircraft icing tests are a small fraction of their work load. Most of the facilities are large refrigerated cold rooms, where the test aircraft or component is tied down on the floor and subjected to a fan blown spray (see fig. 2-C(a)). One of these refrigerated facilities (C-3a) is large enough to permit a full scale aircraft to be tested with partial immersion in an icing cloud.

Figure 2-C(b) describes the unique Helicopter Spray Rig (C-1), which is located near Ottawa, Canada. In this case the test Helicopter hovers in the wind blown spray. A large engine test facility (C-2) has been listed here



in addition to being listed in table B. On Mt. Washington, equipment is tied down and subject to severe natural icing conditions (C-5). The refrigerated cold rooms can perform icing tests all year, whereas facilities C-1, C-2, and C-5 are essentially limited to winter operation. The LWC and drop size is adequate for ICE or FR tests (whichever is applicable for a given facility).

Tankers for flight tests. - There are six (6) tankers listed in table D; one of these (D-5) has just been added, and (D-1b) is not yet in operation. Figure 2(D) describes the HISS tanker (D-2) and its test helicopter; all other tanker facilities are fixed wing aircraft. There are differences in the shape, size, and location of the spray manifold. Icing tests can be run with most fixed wing aircraft in any season by merely flying at the altitude where the desired temperature occurs. The limited altitude capability of helicopters and some G/A aircraft limits the icing test season to the winter season. Most of the tankers are dedicated to do icing tests full time. There have been many problems with these facilities. One of the most serious was large droplets in the spray. Excessively large droplets (larger than 100 microns) are usually easy to spot because the entire unheated nose of the aircraft will ice up, whereas the small droplets in natural icing will only cause the small stagnation region of the unheated blunt nose to accumulate ice. Tests were recently performed on the spray nozzles from the Army HISS and Air Force tankers in the NASA IRT (A-1a). The present military tanker nozzles were found to produce droplets that were 2 to 20 times too large, relative to the 20 micron goal. Fortunately, some of the nozzles tested produced the desired droplet size at reasonable air and water pressures (ref. 8). Therefore, the droplet problem of the entire tanker fleet is on its way to a solution. The icing cloud from all of these tankers tends to be small and non-uniform, with the test aircraft weaving about within the icing cloud; this causes the LWC to vary with time. To partially account for this difficulty a time averaged measurement of the LWC (e.g., an ice accretion measurement) should be made at the location where the critical ice accretion occurs. Another problem is that most of these tankers are not readily available. The Flight systems tanker (D-5) is a recent welcomed addition to the fleet, because it is available for hire to all.

#### Availability and Cost

Availability and charges vary greatly among facilities, and from test to test. The best recommendation is to first use the tables to select the facilities that might fit your needs, then discuss your particular test with the technical contact person (also noted in the tables) for each of those facilities.

#### CURSORY EVALUATION OF ICING FACILITIES

The adequacy of existing Icing Simulation Facilities, in performing the various types of icing tests listed in table 2, is judged in this section. Deficiencies are cited and some short term corrective measures are briefly discussed. These cursory evaluations are based upon: the data in the tables, additional information and opinions from the technical people working with the facilities, and the partial evaluations made in references 9 and 10.



Facilities to test instrumentation. - There are several excellent small government and company facilities for R&D and certification tests or icing instrumentation, (e.g., A-4b, A-5, A-3, and A-7). The first two have the advantage of being able to cover a broad range of air speed, altitude and cloud conditions. In addition, the larger facilities often can inexpensively run instrumentation tests along with another test.

Engine test facilities. - Table B indicates that there are many engine test facilities that can do icing tests, and most of these have excellent capabilities for testing engines over the whole FAR 25 envelope. Nevertheless there are some apparent deficiencies. Column 3 on table B indicates that there are very few facilities that can generate engine-damaging-solid ice particles (from hail and snow to ice chunks). Snow, which is a problem for some inlets, can not be simulated in any facility. A facility is needed to test very large jet engines. This need should be satisfied by the ASTF (see B-1c), which is planned to be built at AEDC in 1983. The engine test facilities that exist today are nearly all sized for turbofan and turbojet engines. A turboprop or G/A propeller engine would be difficult to test in most of these facilities because of the prop size and the very large airflow that must be cooled in these once through-engine facilities. Smaller turboprops could be handled by some of the facilities (e.g., B-9, outdoor mode; B-3; and 3 meter diameter prop engines have been run in the diffuser of A-1). There is no facility for large high speed turboprops; however the one proposed by NASA (A-1b) could again handle the task.

Facilities for fixed wing aircraft. - Certification flight tests in natural icing are expensive but reasonable for long range aircraft that can fly to an area and altitude where icing is likely. But for short range aircraft (e.g. General Aviation), such flights are prohibitively expensive.

All fixed wing aircraft require simulation facilities for R&D icing testing and some certification testing. Short range aircraft use simulation facilities, even for some of their certification testing. The best mix of icing facilities for the near term appear to be the fixed wing tankers (table D) and the three ground facilities as outlined below.

#### RECOMMENDED PRIMARY FACILITIES FOR FIXED WING AIRCRAFT (NEAR TERM)

##### Flight Tests

Natural Icing

Long range aircraft: reasonable for certification tests

Short range: only minimal programs affordable

Flight tankers

##### Ground Tests

Full scale components at high speeds: (B-1a)

Full scale aircraft at very low speeds: (C-3a)

Full scale components at moderate speeds: (A-1) and (A-2)

↑  
Increased  
cost  
↓



Tanker aircraft need technical improvements (already discussed), additional experimental verification of the validity of this testing technique, and greater availability. Three ground facilities are required for R&D tests because no one existing facility covers the required range of size, air speed and altitude. For icing testing of full scale aircraft (but at very low velocities), a good choice is the Eglin cold rooms (C-3a). Full scale aircraft components (e.g., wings, inlets, etc.) can be tested at moderate speeds in the NASA IRT (A-1a) or the smaller tunnel at Lockheed (A-2). Most severe icing conditions occur at low speeds and low altitudes, where these facilities operate. But if icing tests of full scale aircraft components are required at high speed and/or high altitude, then the AEDC free jet (B-1b) should be considered. It should be pointed out that the large wind tunnel rehabilitation proposed by NASA (A-1b) can handle all three requirements of large size, high speed and high altitude; but this facility wouldn't be available until 1987. Scaling laws are often used to compensate for limitations in the speed, altitude or size of a facility, or limitations in the icing cloud produced; however, the icing scaling laws have not been adequately verified experimentally.

Facilities for helicopters. - Performing flight tests on helicopters in natural icing is extremely costly, because the limited range and altitude of the helicopter makes it difficult to find icing conditions. Therefore icing simulation facilities are needed for the bulk of the icing tests; perhaps even including certification tests (ref. 5).

The engine, inlet and the fuselage components can be readily handled by existing engine test facilities and by the icing facilities used for fixed wing aircraft. The effect of the rotor can often be handled by using a reasonable angle of attack.

This is not the case for the rotor. Icing test facilities for the main rotor are not readily available, mainly because of its great size (12 to 18 meter diameter). Another difficulty is that the ice on the blades is subject to velocities ranging from  $M = 0$  to 0.8, and to large centrifugal forces.

A number of icing simulation facilities and test rigs have been proposed and used to do rotor icing testing in the near term; these are listed and described in the following table in their approximate order of: increasing experimental control and data confidence, and decreasing cost, but decreasing flight icing simulation accuracy.



TABLE OF ROTOR ICING TEST METHODS IN NORTH AMERICA (NEAR TERM)

Method	Types of tests	Problems
A. Natural icing flights (e.g., all companies)	Helicopter flight tests	Winter only. Hard to find desired icing conditions, so test programs expensive and long before you get data of high confidence.
B. HISS Tanker (US army)	Helicopter flight tests in spray cloud	Winter only. Somewhat less expensive than natural flights. It is assumed that the drop size and cloud size, etc. are made acceptable. Needs verification.
C. Ottawa spray rig (NRC)	Helicopter flight tests at very low forward speeds in ground level spray cloud	Winter only. Closed after 1985. Relatively inexpensive, relatively good control of conditions. Questions raised about simulation and using results for higher forward speeds. Needs verification.
D. Large cold room (Eglin AFB)	Helicopter tie down tests at near zero forward speeds	All year. More expensive than C. Many practical problems surfaced when it was tried.
E. Scale model rotor in icing wind tunnel (NASA IRT)	Ice accretion and its affect on rotor performance. Icing scaling laws suggest that this should work.	Scaling laws for icing have not been adequately verified experimentally. Smallest drop sizes presently produceable permit models no smaller than 1/5 scale. Deicing systems can not be scaled down readily. Needs verification.
F. Rotor blade segment or tail rotor on a rotating rig in icing tunnel (NASA IRT)	Main rotor blade segment of nearly full scale chord on rotating rig to test deicing system operation and shedding at conservative conditions. Also full to nearly full scale tail rotors	If you match G forces, the blade velocities are very low. Needs verification. Small tail rotors should be closely simulated.
G. Oscillating or fixed airfoil in icing tunnel (NASA IRT)	Full scale blade segment tested with periodic or fixed angle of attack (for ice accretion, aero-performance and deicing system performance) in the absence of G forces, but with blade bending and twisting	The maximum airspeed of the IRT is only $M = 0.4$ , which is too low to determine results in the critical outer half of the rotor. No G forces, therefore shedding not true but conservative. Needs verification.



Certification types of tests tend to be performed on the facilities listed on the top half of the table, whereas R&D tests tend to be accomplished on the lower half. But there is considerable uncertainty; verification tests are needed in order to determine where these simulation facilities adequately simulate natural icing on the rotor at the various flight conditions. For example, the HISS tanker - until recently - generated icing clouds with droplets that were about 10 times larger than those of natural icing (ICE); as a consequence the icing results were closer to those produced by freezing rain (FR). The new spray nozzles for the HISS now produce the correct 20 micron drop size (ref. 8).

The Ottawa spray rig (B in the above table) is a valuable facility; but it may not be available after 1985. It is also limited to near-zero speeds, although many users have tried to extrapolate their results to cruising speeds with mixed success.

The dynamic and aerodynamic degradation of a rotor in icing could be determined in principle on a model rotor in an icing wind tunnel. Unfortunately icing tests of model rotors suffer from the following difficulties. First, existing tunnels are too small. Figure 3 indicates that the largest models that can be tested in the largest wind tunnel (A-1a) with proper aerodynamics would be 1/6 th to 1/12 th scale models. These models would require smaller droplets, for proper scaling, than can be made with present nozzles. Furthermore, these models would have to be built from scratch at very high cost, because the model rotors used by the helicopter companies are larger. The proposed large wind tunnel (A-1b) would be large enough to avoid this difficulty but this will not be available until 1987. And finally, the icing scaling laws have not been validated experimentally.

The test rigs for rotor icing are unable to simulate all the forces acting on the accreted ice. Specifically, a rotating blade segment (F in the above table) will have very low blade velocities if the G forces are matched. Thus any test of a deicer system will be conservative and will require analysis in order to relate the results to the actual conditions on a full scale rotor. The oscillating blade rig (G in the above table) also gives a conservative simulation, primarily because no G forces are present. The main purpose, of the test rigs (F and G) are in the development of rotor icing and deicing analyses, and for conservative development tests.

The facilities and test rigs in the above table are, or will be, available soon. Two major facilities to do icing tests on full scale rotors have been seriously proposed for the long term. One is an improved tanker using either a large helicopter or a large slow speed fixed wing transport. The other is a very large slow speed test section for facility (A-1b).

The recent loss of the small high speed wind tunnel of NRC (A-4b) is a serious handicap toward acquiring vital data on the aerodynamic degradation caused by icing on 2D rotor airfoils. A replacement for this facility is needed.



## APPENDIX - ICING CLOUD MEASUREMENTS

In the course of making this survey of facilities, a number of concerns about measurements were brought out, which will be briefly described in this section. They are: droplet size measurements, the need for comparable liquid water contents (LWC) in all facilities, the uniformity of the LWC and drop size across the icing spray cloud, and the relative humidity and temperature of the air within the cloud.

LWC standard. - The survey brought out the fact that it is difficult to compare icing results from different facilities. Part of the reason for this difficulty is that the accuracy of LWC instruments is often only about  $\pm 20$  percent. Another reason is that there is no standard instrument that can be used in all facilities. It has been suggested that a thin blade (0.32 cm thick x 1.9 cm chord) be used as an interim standard because it is adequately accurate over a large range of conditions, and easy and inexpensive to make and use. The blade has been described and investigated in detail by Stallabrass (ref. 11). The blade is exposed to the cloud for only 30 seconds and the air is cold ( $< -12^{\circ}\text{C}$ ) in order to avoid thermal problems (ref. 11). The thickness of the ice accretion on the thin edge is measured by a micrometer; the LWC is then determined by a simple calculation. With such a common standard, the LWC calibration curves for all facilities and LWC instruments could be inexpensively made consistent. A more accurate but more expensive standard would be a thin rotating cylinder (0.32 cm diam rod) that is exposed to the cloud for a short time.

Uniformity of LWC and drop size. - In all simulation facilities, it is usually desirable to have a uniform LWC and drop size across the cloud. With reasonable care in the design and maintenance of spray nozzle arrays, the drop size should be reasonably uniform, especially with small droplets. Achieving uniformity of the LWC is inherently more difficult. Because of turbulent mixing, the sprays from each nozzle undulate so that the accumulation of ice at a given point is due to the time varying LWC from many nozzles. In tanker tests, the test aircraft also undulates within the spray cloud. Fortunately, the ice build up is a time averaging process, which moderates this difficulty. Even in the well controlled wind tunnels, a few spray nozzles must be moved from time to time in order to keep the LWC across the cloud reasonably uniform. It proved to be difficult during the survey to quantitatively establish how uniform each facility's cloud was. Part of the reason for this is that there is no standard for uniformity. A practical definition of the uniform region would be wherever the time average LWC was within  $\pm 20$  percent of the LWC at the center of the cloud. The uniformity of ground facility sprays is usually determined by the uniformity of the ice accretion on an array of cylinders. The determination is based upon visual inspection or a measurement of the uniformity of the mass of ice accreted.

Droplet size. - A cursory look at column 12 in tables A through D indicates that the volume-median drop size is measured by a variety of instruments, ranging from the "tried-and-true" older methods (e.g., rotating cylinders and oil slide) to modern methods (e.g., laser spectrometers and laser holographs). The relative accuracy and practicality of these instruments is still being debated. The consensus of users (verbal and reports) indicates that the accuracy of the modern instruments appear to be  $\pm 3$  to 6 microns, for the drop sizes typical of ICE (refs. 12 and 13). Most of the



old instruments can't give real time results, and they may not be quite as accurate as the modern instruments; on the other hand, they are far less expensive to use if the amount of the data is modest. Two other points to consider are: How often must the drop size be measured, and what accuracy is required. For example, a 5 micron error might be acceptable in a Certification test requiring 20 microns. In an icing simulation facility, drop size measurements need not be made very often. Measurements have indicated that the spray in the NASA IRT has produced the same drop size for more than 20 years with only minimal maintenance and demineralized water.

Relative humidity and temperature of the air in the spray cloud. - Accurate measurements of the relative humidity and temperature of the air inside of the spray cloud are extremely difficult. The slightest amount of moisture will drive the relative humidity from 0 to 100 percent at the low air temperature of icing tests. Often, the best approach is to measure the conditions outside of the cloud and use a heat balance to calculate (ref. 13) the relative humidity of the air in between the droplets of the spray cloud.

Recommendation. - A comprehensive experimental comparison of LWC, temperature, drop size and relative humidity instruments should be made in an icing tunnel, where the spray cloud is relatively repeatable. Such a test will determine the relative accuracy (not absolute accuracy) of the various instruments (both modern and old style) and their limitations for various applications.

Along these lines it is also recommended that one small icing facility be used as the standard reference cloud, where instruments and their calibrations could be occasionally checked out. This would help standardize measurements made in ground facilities and in flight. This approach takes advantage of the repeatability of spray clouds in ground facilities, and admits that there may never be a cloud measurement whose accuracy is absolutely known.



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## ABBREVIATIONS, AND FOOTNOTES FOR TABLES

<sup>a</sup>Types of icing and anti-deicing tests run: CPU = complete propulsion unit; EDC = engine direct connect; FSC = full-scale aircraft component (including wing, tail, fuselage, windshield, stores, gear, etc.); MS = model scale tests and instrumentation; IA = ice adhesion; CP = cloud physics; R = rotating experiments (e.g., helicopter rotor models and propellers); G = ground transport and installations in freezing rain; FS = full-scale aircraft; FLT = flight tests of aircraft; I = inlets with suction; P = complete propeller engines; H = human physiological experiments.

<sup>b</sup>Whether simulated: ICE = icing cloud environment; SI = solid ice particles; FR = freezing rain; R = rain; N = natural icing; S = snow.

<sup>c</sup>Parameter ranges vary with conditions; request operating envelopes from contact person.

<sup>d</sup>Modification to do this has been seriously proposed.

<sup>e</sup>Tests in progress to extend these limits.



## CAPABILITIES OF ICING SIMULATION TEST FACILITIES IN NORTH AMERICA

[Capabilities estimated by technical contact person for each facility.]

## A. WIND TUNNELS

Facility no.	Facility name (Location)	Types of icing tests run  (a)	Weather simulated  (b)	Type of facility	Size (see sketches), m		Range of parameters used in icing tests <sup>c</sup>					Instruments used for local drop size and (LWC)	Technical person to contact	Test season	Comment
					Test chamber	Uniform icing cloud	Air speed, km/hr	Min. total air temperature, °C	Altitude, m	LWC, g/m <sup>3</sup>	Vol. med. drop size, μm				
A-1	NASA - Lewis Research Center (Cleveland, OH) (a) IRT	FSC, I MS, R, IA, P <sup>d</sup>	ICE, FR <sup>d</sup>	Wind tunnel	H = 1.8 W = 2.7 L = 6	$h_u = 0.9$ $w_u = 1.5$	10 to 470	-30	0	<sup>e</sup> 0.5 to 3.0	<sup>e</sup> 11 to 25	Rot. cycls. and various modern instruments (rot. cyl.)	J. Reinmann (216)433-4000	All year	Modernization nearly complete
	(b) AWT - Rehabilitation	FSC, I, MS, R, CPU, G, P	ICE, FR, SI	Wind tunnel	D = 6 D = 14	$d_u = 4.5$	10 to M = 1.0 Up to 95	-30	0 to 15 000	0.2 to 3.	10 to 50+ (nozzles changed)	Various modern instruments	J. Yuska (216)433-4000	All year	Proposed for 1987
A-2	Lockheed (Burbank, CA)	MS, FSC, I	ICE	Wind tunnel	H = 1.2 W = 0.8	$h_u = 0.5$ $w_u = 0.3$	90 to 340	-20	0	0.7 to 4.0	10 to 25	Rot. cyls. (rot. cyl.)	B. Robinson (213)847-6121	All year	-----
A-3	Boeing (Seattle, WA)	MS, FSC, I	ICE	Wind tunnel	H = 0.5 W = 0.4 L = 0.9	$h_u = 0.4$ $w_u = 0.3$	180 to 370	-30	0	0.3 to 5.0	10 to 50 (nozzles changed)	Rot. cycls., oil slide (sm. cyl.)	R. Wilder (206)342-4776	All year	-----
A-4	NRC (Ottawa, Canada) (a) Large Tunnel	FSC, MS, I, G	ICE, FR	Wind tunnel	H = W = 1.4	$h_u = w_u = 1$	140 to 160 90 to 110	-28	0	-----	15 to 30 (nozzles changed)	Rot. cycls., oil slide (rot. cyl.)	A. Price (613)993-2371	All year	Dismantled in 1979
	(b) High Speed	MS, FSC	ICE	Wind tunnel	H = W = 0.3	$h_u = w_u = 0.25$	90 to M = 0.8	-30	0 to 9 000	0.2 to 2.	15 to 25	Oil slide (rot. cyl.)	A. Price (613)993-2371	All year	To be mothballed
A-5	AEDC Research Cell (Arnold AFS, TN)	FSC, MS	ICE	Free jet	D = 0.9 d = 0.3	$d_u = 0.3$	150 to M <sub>jet</sub> = 0.7	-30	0 to 15 000	0.2 to 3. +	15 to 30	Various modern instruments	J. Hunt (615)455-2611	All year	-----
A-6	Rosemount (Minneapolis, MN) (a) Low Speed	MS	ICE	Wind tunnel	H = 0.15 W = 0.1 L = 0.3	$h_u = 0.1$ $w_u = 0.07$	90 to 170	-30	0	0.2 to 1.5	20 to 40	Oil slide (rot. cyl.)	R. DeLeo (612)941-5560	All year	Rosemount use only
	(b) High Speed	MS	ICE	Wind tunnel	H = 0.15 W = 0.3 L = 0.8	$h_u = w_u = 0.1$	90 to 740	-25	0 to 3 000	0.1 to 3.0	10 to 40	Oil slide (rot. cyl.)	R. DeLeo (612)941-5560	All year	Rosemount use only
A-7	Frost Tunnel (Univ. of Alberta, Canada)	MS, IA	ICE	Wind tunnel	D = 0.5 (Octogano) L = 0.9	$d_u = 0.3$	10 to 240	-20	0	0.4 to 3.0	20 to 50 (nozzles changed)	Oil slide (rot. cyl.)	E. Gates (403)432-5180	All year	-----
A-8	UCLA Cloud Tunnel	MS, CP	ICE, R	Vertical wind tunnel	H = W = 0.15 L = 0.5	$h_u = w_u = 0.1$	0 to 55	-30	0	0.1 to 3.	2 to 50	Various modern instruments	H. Pruppacher (213)825-1038	All year	Free particle suspension
A-9	Army Natick R&D (Natick, Mass.) Climatic Chamber	G, FSC, H	FR, R, S	Wind tunnel	H = 3 W = 4.5 L = 18	-----	4 to 65	-30 and lower	0	10 cm rain/hr	Not measured (rain gauge)	M. Kellberg (617)653-1000	All year	Mainly physiological tests of humans	



# B. ENGINE TEST FACILITIES

[Note that most free jets can do wind tunnel types of tests.]

Facility no.	Facility name (Location)	Types of icing tests run  (a)	Weather simulated  (b)	Type of facility	Size (see sketches), m		Range of parameters used in icing tests <sup>c</sup>					Instruments used for local drop size and (LWC)	Technical person to contact	Test season	Comment
					Test chamber	Uniform icing cloud	Air speed, km/hr	Min. total air temperature, °C	Altitude, m	LWC, g/m <sup>3</sup>	Vol. med. drop size, μm				
B-1	AEDC (Arnold AFS, TN) (a) ETF	EDC	ICE	Direct connect d = 1.5	D = 3.7 or 4.5 L = 11	Spray bars sized to engine	0 to M = 0.7+	-30	0 to 15 000	0.2 to 3. +	15 to 30	Various modern instruments	J. Hunt (615)455-2611	All year	-----
	(b) Free Jet	CPU, FSC I, MS	ICE	Freejet d = 1.5	D = 3.7 or 4.5 L = 11	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0 to 15 000	0.2 to 3. +	15 to 30	Various modern instruments	J. Hunt (615)455-2611	All year	-----
	(c) ASTF	CPU, FSC, I	ICE	Freejet d = 2.7	D = 8 L = 18	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0 to 15 000	0.2 to 3. +	15 to 30	Various modern instruments	W. Bates (615)455-2611	All year	Planned for 1983
B-2	Detroit Diesel Allison (Indianapolis, IN) (a) Comp. Test Facility	Inlet and compressor stage	ICE	Freejet Direct connect d = 0.5	D = 2.3 L = 9	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0 0 to 6 000	0.2 to 3.5	15 to 40	Rotating cylinders	W. Stiefel (317)243-4066	All year	-----
	(b) Small Engine Facility	EDC	ICE	Direct connect	D = 0.45 L = 1.2	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0 to 6 000	0.2 to 3.5	15 to 40	Rotating cylinders	W. Stiefel (317)243-4066	All year	-----
B-3	GE Cross-wind Facility (Peebles, OH)	CPU, P <sup>d</sup> , R <sup>d</sup>	ICE	Free-jet outdoors d = 7.0	Outdoors	d <sub>u</sub> = 4.5	90	Ambient air to -20	0	0.4 to 3.5	15 to 50	Knollenberg spectrometer (rot. cyl.)	R. Keller (513)243-4483	Winter	-----
B-4	P&W Altitude Facilities (E. Hartford, CT) (a) Large	EDC, I	ICE	Direct connect	D = 5.5 L = 10	Spray bars sized to engine	0 to M = 0.5	-25	0 to 6 700	0.2 to 9.0	15 to 40	Oil slide	J. Barlock (203)565-2091	All year	-----
	(b) Smaller	EDC, I	ICE	Direct connect	D = 3.7	Spray bars sized to engine	0 to M = 0.5	-30 and lower	0 to 6 700	0.2 to 9.0	15 to 40	Oil slide	J. Barlock (203)565-2091	All year	-----
	(c) P&W Sea Level Facility	EDC	ICE	Direct connect	Varies with test cells	Spray bars sized to engine	0 to M = 0.5	-20 (ambient)	0	0.2 to 9.0	15 to 40	Oil slide	J. Barlock (203)565-2091	Winter	-----
B-5	McKinley Climatic Lab Engine Test Cell (Eglin AFB, FL)	CPU, FSC	ICE, SI FR, R	Fan blown spray indoors	H = 7.5 W = 9 L = 40	h <sub>u</sub> = 3 w <sub>u</sub> = 6	0 to (30 to 70)	-36 and lower	0	0.1 to 3. 12 to 60 800 to 1500 (nozzles changed)	Particle interferometer (rot. cyl.)	R. Tolliver (904)882-3626	All year	-----	



B. Concluded. ENGINE TEST FACILITIES

[Note that most free jets can do wind tunnel types of tests.]

Facility no.	Facility name (Location)	Types of icing tests run	Weather simulated	Type of facility	Size (see sketches), m		Range of parameters used in icing tests <sup>c</sup>					Instruments used for local drop size and (LWC)	Technical person to contact	Test season	Comment
					Test chamber	Uniform icing cloud	Air speed, km/hr	Min. total air temperature, °C	Altitude, m	LWC, g/m <sup>3</sup>	Vol. med drop size, μm				
B-6	Naval Air Propulsion Facility (Trenton, NJ) (a) Five small engine cells	EDC, CPU, I, FSC, MS	ICE, SI, FR, R	Free jet d = 0.6	H = W = 3 L = 6	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0 to 15 000	0.1 to 2.	15 to 50 (nozzles changed)	Knollenberg spectrometer and OAP (rot. cyl.)	Resource Mgr. (609)896-5655	All year	-----
	(b) Two large sea level cells	EDC, CPU, I, FSC, MS	ICE, SI, FR, R	Free jet d = 1.2	H = 4.5 W = 7 L = 17	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0	0.1 to 2.	15 to 50 (nozzles changed)	Knollenberg spectrometer and OAP (rot. cyl.)	Resource Mgr. (609)896-5655	All year	-----
	(c) Three large altitude cells	EDC, CPU, I, FSC, MS	ICE, SI, FR, R	Free jet d = 1.2	D = 5 L = 9	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0 to 15 000	0.1 to 2.	15 to 50 (nozzles changed)	Knollenberg spectrometer and OAP (rot. cyl.)	Resource Mgr. (609)896-5655	All year	-----
B-7	Teledyne Altitude Cells (Toledo, OH) (a) Chamber 1	CPU, EDC	ICE, SI, FR, R	Free jet or direct connect, d = 0.2	D = 2.7 L = 5	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0 to 15 000	Up to 3.	15 to 25	Oil slide	R. Trauth (419)470-3236	All year	-----
	(b) Chamber 2	CPU, EDC	ICE, SI, FR, R		H = 2.5 W = 2.5 L = 4	Spray bars sized to engine	0 to M = 0.7+	-30 and lower	0 to 15 000	Up to 3.	15 to 25	Rotating cylinders	R. Trauth (419)470-3236	All year	-----
B-8	Avco Lycoming (Stratford, CT) (a) Component Facility	EDC	ICE, FR	Direct connect d = 0.4	-----	Spray bars sized to engine	0 to 370	-30 and lower	0	0.1 to 3.	15 to 40	Oil slide (rot. cyl.)	J. Sherman (203)378-8215	All year	-----
	(b) Engine Test Facility	EDC	ICE, FR	d = 0.4 d = 1.2	W = 3.7 H = 2.7 Outdoors	Spray bars sized to engine	0 to 200	-30 and lower -20	0	0.1 to 3.	15 to 40	Oil slide (rot. cyl.)	J. Sherman (203)378-8215	All year Winter	-----
B-9	NRC, Cell #4 (Ottawa, Canada)	EDC, CPU	ICE, SI	Free jet or direct connect d = 0.75	H = W = 7.5	Spray bars sized to engine	0 to 650	-20 and lower	0	0.2 to 2.	15 to 40	Oil slide (rot. cyl.)	W. Grabe (613)993-2214	Winter	-----
		CPU, P		d = 2.0			0 to 93	Ambient							
B-10	Garret Icing Facilities: (Phoenix, AZ) Cell 1, Cell 2, and Cell 3	CPU, I EDC, FSC, P	ICE, SI	Free jet or direct connect, d = 1.0 to .1	H = 3 W = 4 L = 10	Spray bars sized to engine	M = 0.01 - 0.7	-30 and lower	0 to 15 000	0.1 to 6.0	10 to 50	Rot. cyls. (Rot. cyls.)	J. Pyne (622)267-3853	All year	-----



C. LOW VELOCITY FACILITIES

Facility no.	Facility name (Location)	Type of icing tests run (a)	Weather simulated (b)	Type of facility	Size (see sketches), m		Range of parameters used in icing tests <sup>c</sup>					Instruments used for local drop size and (LWC)	Technical person to contact	Test season	Comment
					Test chamber	Uniform icing cloud	Air speed, km/hr	Min. total air temperature, °C	Altitude, m	LWC, g/m <sup>3</sup>	Vol. med. drop size, μm				
C-1	NRC Helicopter Spray Rig (Ottawa, Canada)	FLT(helicopters in hover)	ICE, FR	Wind blown spray outdoors	D = ∞	Spray manifold h <sub>s</sub> = 4.5 w <sub>s</sub> = 23	Ambient wind, 20 to 45 (gusty)	-20 (ambient)	0	0.1 to 0.8	30 to 60	Oil slide (rot. cyl.)	T. Ringer (613)993-2439	Winter	To be mothballed in 1985
C-2	G. E. Cross Wind Facility (Peebles, OH)	CPU, P <sup>d</sup> , R <sup>d</sup>	ICE, FR	Free jet outdoors	D = ∞	d <sub>u</sub> = 4.5	90	-20 (ambient)	0	0.4 to 3.6	15 to 50	Knollenberg spectrometer (rot. cyl.)	R. Keller (513)243-4483	Winter	-----
C-3	McKinley Climatic Lab (Eglin AFB, FL) (a) Main Chamber	FS, R <sup>d</sup>	ICE, SI FR, R	Fan blown spray indoors	H = 21 W = 76 L = 76	Spray manifold h <sub>s</sub> = 3 w <sub>s</sub> = 9	0 to (30 to 75 <sup>e</sup> ) (depending on L <sub>B</sub> )	-30 and lower	0	0.1 to 3	12 to 60 800 to 1500 (nozzles changed)	Particle interferometer (rot. cyl.)	R. Toliver (904)882-3626	All year	Largest cold room
	(b) Engine Test Cell	CPU, FSC	ICE, SI FR, R	Fan blown spray indoors	H = 7.5 W = 9 L = 40	Manifold h <sub>s</sub> = 3 w <sub>s</sub> = 6	0 to (30 to 75) (depending on L <sub>B</sub> )	-30 and lower	0	0.1 to 3	12 to 60 800 to 1500 (nozzles changed)	Particle interferometer (rot. cyl.)	R. Toliver (904)882-3626	All year	-----
	(c) All Weather Room	FSC	ICE, SI FR, R	Fan blown spray indoors	H = 4.5 W = 6.5 L = 12	Manifold h <sub>s</sub> = 3 w <sub>s</sub> = 3	0 to (30 to 75) (depending on L <sub>B</sub> )	-30 and lower	0	0.1 to 3	12 to 60 800 to 1500 (nozzles changed)	Particle interferometer (rot. cyl.)	R. Toliver (904)882-3626	All year	-----
C-4	U.S. Army CRREL Cold Room (Hanover, NH)	FSC, MS R, IA	ICE, SI FR, R	Fan blown spray indoors	H = 1.1 W = 0.7 L = 1.5	-----	0 to 20	-30 and lower	0	1 to 2.5	10 to 60	Cascade impactor	G. Ashton (603)643-3200	All year	-----
C-5	Mt. Washington Observatory (Gorham, NH)	FS, CP, MS	Natural icing of tied down equipment on top of mountain				0 to 180 (gusty)	-20 and lower	1800	Generally severe natural conditions		Rotating cylinders	J. Howe (603)466-3388	Fall to spring	-----
C-6	U.S. Navy PMTC (Pt. Magu) Climatic Hanger	FSC, FS, G	R, FR	Fan blown spray indoors	H = 7.6 W = L = 18	h <sub>s</sub> = w <sub>s</sub> = 1.2	0 to 75	-30 and lower	0	30 cm rain/hr	500 to 4500	Oil slide (rain gauge)	D. Everett (805)982-8011	All year	-----
			S							5 cm snow/hr	50 to 100				
C-7	Acton Environmental Test Corp. (Acton, Mass.)	G	R, FR, S <sup>d</sup>	Fan blown spray indoors	H = 6 W = 4.5 L = 7.5	d <sub>s</sub> = 2.5	0 to 45	-30 and lower	0	10 cm rain/hr	1000 to 4000	Not measured (rain gauge)	R. Gilfoy (617)263-2933	All year	-----
C-8	NRC (Ottawa, Canada) Cold Chamber #1	G, FS	FR, S <sup>d</sup>	Fan blown spray indoors	H = 4.3 W = 4.5 L = 15.2	d <sub>s</sub> = 1.2 to 2.5	0 to 55	-30 and lower	0	0.3 cm rain/hr	500 to 1000	Screen method (accumulation rate)	T. Ringer (613)993-2439	All year	-----
	NRC (Ottawa, Canada) Cold Chamber #2	G, FS	FR	Fan blown spray indoors	H = 5 W = 5 L = 7	d <sub>s</sub> = 1.8	0 to 55	-30 and lower	0	0.3 <sup>d</sup> cm rain/hr	500 to 1000	Screen method (accumulation rate)	T. Ringer (613)993-2439	All year	-----
C-9	Wyle Labs (Norco, CA) Cold Room	G, FSC	FR	Fan blown spray indoors	H = 5 W = 4.5 L = 11	-----	0 to 35	-30 and lower	0	12 cm rain/hr	-----	-----	M. Clark (714)737-0871	All year	-----
C-10	Arctec Canada Ltd. (Ottawa, Canada) Cold Room	G, IA	FR <sup>d</sup> , S <sup>d</sup>	Fan blown spray indoors	H = 3.7 W = 5.5 L = 9	-----	to 35	-30 and lower	0	-----	-----	-----	A. Nawwar (613)592-2830	All year	-----



# D. TANKERS FOR FLIGHT TESTS

[In addition, most airframe companies can test aircraft in natural icing.]

Facility no.	Facility name (Location)	Types of icing tests run	Weather simulated	Time in icing at high LWC, min	Size of spray, m		Range of parameters used in icing tests <sup>c</sup>					Instruments used for local drop size and (LWC)	Technical person to contact	Test season (find temp. at altitude)	Comment
					At nominal distance $L_B$	Manifold	Air speed, km/hr IAS	Min. total air temperature, °C	Altitude, m	LWC, g/m <sup>3</sup>	Vol. med. drop size, μm				
D-1	Air Force (Edwards AFB, CA) (a) KC 135 Tanker	Flt.	ICE, N	60	At $L_B = 60$ $d = 3$	$d_s = 1.2$	300 to 650 (370 nom.)	-20 (ambient)	1200 to 8000	0.05 to 1.5 0.5 to 32.	28 to 35 200 to 800	Knollenberg spectrometer ( " )	R. Morrison (805)277-3068	All year	Final calibration in 1981
			R, FR												
	(b) C 130 Tanker	Flt.	ICE, N	60	At $L_B = 60$ $d = 5$	$d_s = 1.2$	190 to 390 (280 nom.)	-20 (ambient)	1200 to 8000	0.05 to 1.5 0.05 to 32.	28 to 35 desired 200 to 800	Knollenberg spectrometer ( " )	R. Morrison (805)277-3068	All year	Planned for 1981
			R, FR												
D-2	Army HES Helicopter Tanker (Edwards AFB, CA)	Flt.	ICE, N	30	At $L_B = 50$ $h = 3$ $w = 12$	$h_s = 1.6$ $w_s = 12$	110 to 140 (120 nom.)	-20 (ambient)	600 to 3500	0.1 to 1.0	25 to 30 desired	Knollenberg spectrometer (Leigh)	C. Frankenberg (805)277-2271	Normally winter	Testing to increase cloud size
D-3	Cessna 404 Tanker (Wichita, KA)	Flt.	ICE, R, FR, N	60	At $L_B = 150$ $d = 6$	$d_s = 0.6$ (V-bar)	165 to 330 (260 nom.)	-20 (ambient)	300 to 8000	0.05 to 4.0	20 to 49 (water nozzles)	Gelatin slide (J&W)	D. Hazelwood (316)946-6606	All year	-----
D-4	Piper Cheyenne Tanker (Lock Haven, PA)	Flt.	ICE, FR, R, N	14	At $L_B = 30$ $h = 3$ $w = 5$	$h_s = 1.2$ $w_s = 1.8$	200 to 300 (240 nom.)	-20 (ambient)	300 to 8000	0.1 to 1.7	30 to 50	Gelatin slide (J&W)	J. Bryerton (717)748-6711	Not summer	-----
D-5	Flight Systems T-33 Tanker (Mojave, CA)	Flt.	ICE, R, FR, N	45	At $L_B = 60$ $d = 2.5$	$h_s = 0.3$ $w_s = 0.9$	230 to 420 (370 nom.)	-20 (ambient)	300 to 8000	0.1 to 1.0	17 to 50	Knollenberg spectrometer ( " )	J. Ligon (805)824-4601	All year	-----



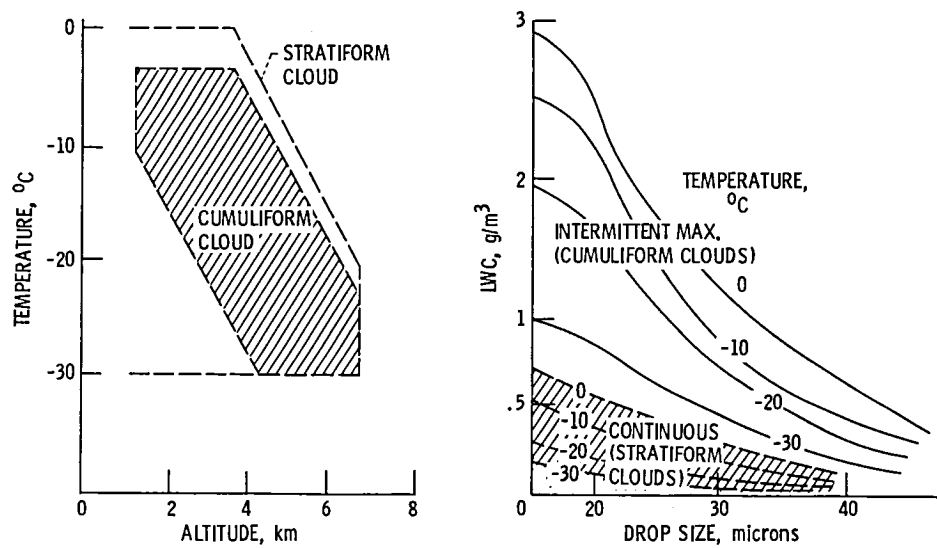
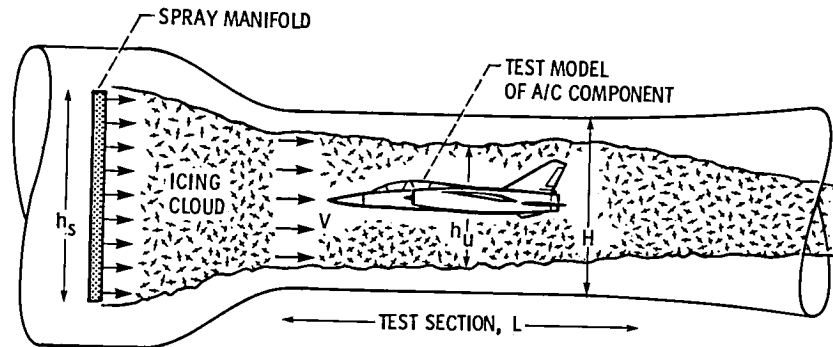


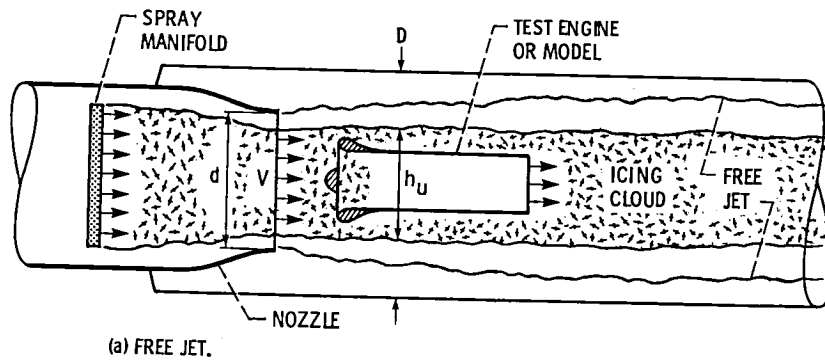
Figure 1. - FAR - 25 Icing certification conditions; 99.9% exceedance probability, ref. 3.



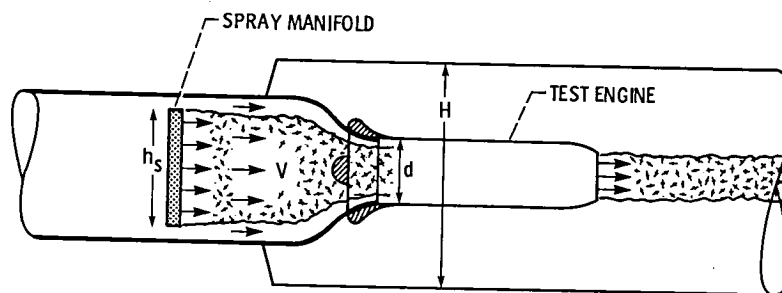
# SCHEMATIC SKETCHES FROM SIDEVIEW



## A. WIND TUNNELS



(a) FREE JET.

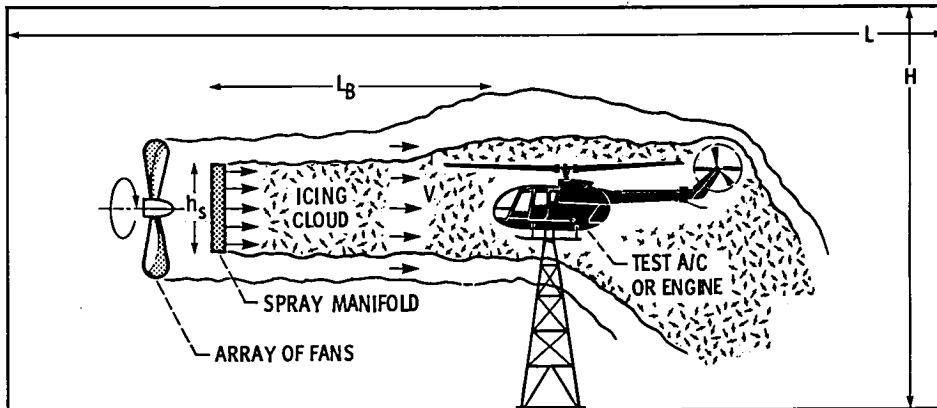


(b) DIRECT CONNECT.

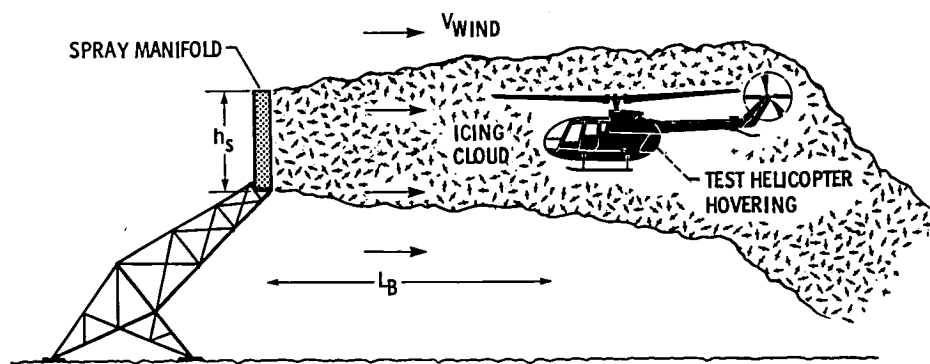
## B. ENGINE TEST FACILITIES

Figure 2 - Types of icing simulation facilities.



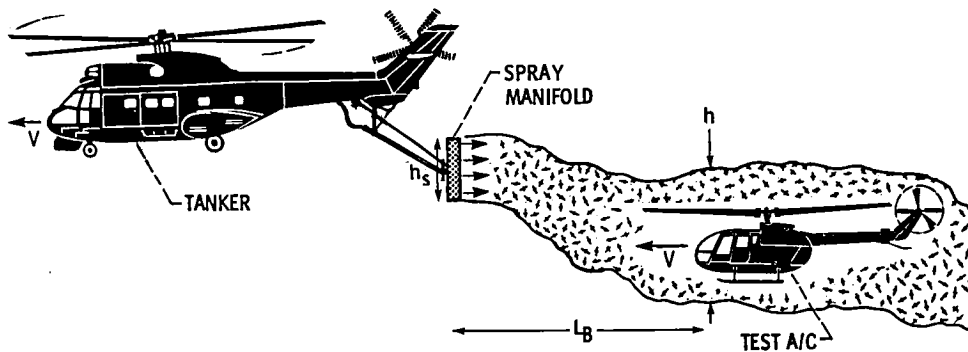


(a) FAN BLOWN SPRAY IN A LARGE ROOM OR OUTDOORS.



(b) WIND BLOWN SPRAY OUTDOORS.

### C. LOW VELOCITY FACILITIES



### D. FLIGHT TESTS WITH TANKER

Figure 2. - Concluded.



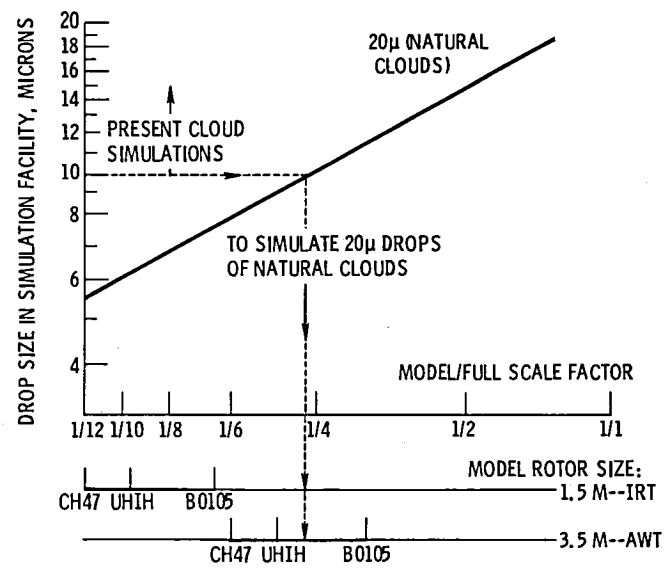


Figure 3. - Effect on drop size on scaling (old style instruments).







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16. Abstract <p>A survey was made of the aircraft icing simulation facilities in North America. This was requested of NASA by several committees concerned with Aircraft Icing. A similar survey of European facilities had already been reported in AGARD advisory report 127. There are 12 wind tunnels, 28 engine test facilities, 6 aircraft tankers and 14 low velocity facilities, that can perform various aircraft icing tests full or part time. The survey determined the location and size of the facility, its speed and temperature range, icing cloud parameters, and the technical person to contact. These results are presented in tabular form. The capabilities of each facility were estimated by its technical contact person. The adequacy of these facilities for various types of icing tests is discussed.</p>					
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